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PRINCIPLES OF HIGHWAY CAPACITY RESEARCH

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HIGHWAY DIVISION

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PAPERS

PRINCIPLES OF HIGHWAY CAPACITY RESEARCH

By O. K. Normann[1]

Synopsis

The problem of highway capacity design has relied mainly on empirical factors developed by the road builder. Very few factual data have been available and the literature contains few helpful references.

This paper summarizes the results of research in highway capacity. The types of investigations that were conducted and the conclusions derived are listed and discussed. These include investigations of overtaking and passing practices, motor vehicle performance, driver behavior, and traffic flow at intersections.

The factors of desired speed and practical capacity of roads are related to the effects of various limitations. Suggestions are made as to the practical application of the research data in design and construction.

Introduction

Few engineering problems are of more interest to so many people and have as large effect on their everyday lives as those problems relating to traffic conditions. Almost everyone is aware of the overloaded streets and highways that exist at many places during certain periods. Many are also aware of the fact that some highways will accommodate much higher traffic volumes before becoming congested than others, and that it is more comfortable to travel on certain highways than on others when the density of traffic is a factor. Few drivers, however, have any conception of the roadway width required to accommodate a given volume of traffic or the details of design that are necessary to obtain maximum safety for travel at reasonable speeds. These features are the responsibility of the engineer.

In 1937, however, when a review was made of all literature relating to the effect that various highway design features have on the volume of traffic

Note.—Written comments are invited for publication; the last discussion should be submitted by May 1, 1952.

[1] Chief, Section of Traffic Operations, U. S. Bureau of Public Roads.

that can be accommodated by a highway and the speed and safety of movement, it was astonishing to find that there was little information available that had been based on facts gathered through research. Apparently, engineers engaged in the planning and construction of highways had directed their efforts in the research field almost entirely to improving the strength and life of the structure, and to more economical construction in order to utilize the funds available for highway improvement over the greatest mileage. Their knowledge of the required geometric features was based largely on their own experiences as drivers. There had been little concentrated effort to discover the technical facts relating to the dynamics of flow that are of prime importance if a highway is to serve traffic effectively. These factors involve the effect that various highway design features such as surface and shoulder width, alinement, and gradient have on the safety and economy of operation of individual vehicles, and how the movement of each vehicle is affected by, and in turn affects, the movement of other vehicles in the traffic stream.

History of Capacity Research

The intensive research projects in traffic operations carried out since 1930 by many organizations have resulted in the development of several entirely new principles that provide the basis for highway design standards required to accommodate the needs of traffic. Substituting facts obtained through research for personal opinion has resulted in major changes in the approach to many traffic problems.

It is fortunate that one of the most intensive research projects carried out in the field of traffic operations deals with highway capacity.[2] Basically, this subject concerns the effectiveness of various facilities in the service of traffic and involves the effect on traffic flow of the many elements of highway design, vehicle and driver performance characteristics, and traffic control measures. It is also fortunate that conditions that tend to increase the capacity of a highway also result in improved traffic safety whether they apply to the highway, the vehicle, or the driver.

Considering the scope of the many individual yet interrelated studies that have been conducted to obtain fundamental data, and the comprehensive analyses to which these data have been subjected, it is apparent that the technical facts now available (1951) will permit new highways to be designed or old ones to be revamped with the assurance that highway operating conditions will be consistent with the justifiable needs of traffic. These studies have included the development of new electro-mechanical instruments that have made feasible the collection of data in larger volume and with greater accuracy than was previously possible, and the recording of some types of information that could not otherwise have been obtained. The following are but a few of the more important investigations in traffic operations conducted by the Bureau of Public Roads, generally in cooperation with various state highway departments and other private and public agencies:

[2] "Highway Capacity Manual," by the Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C.

1. Investigations were conducted of overtaking and passing practices on two-lane roads. During these studies, the speed and position of each vehicle in relation to other vehicles on the highway was recorded continuously over a 0.5–mile section. The data was obtained in nine States geographically distributed to include any major differences in driving habits and included actual practices of drivers while performing some 20,000 passing maneuvers. The results showed the physical measurements of time and space involved in performing passing maneuvers with safety, the frequency of maneuvers at various speeds in relation to traffic volumes, and the portion of any section of highway that must be designed to provide for passing. Conversely, the effect of restrictive sight distances in limiting the capacity of a highway was determined.

2. Investigations were made of motor vehicle performance. These included such studies as grade ability, braking ability, and acceleration and turning characteristics of new and used vehicles. The results of these investigations, in combination with other studies, provide information of particular significance in determining the effect that truck loading practices and truck movements have on highway capacity. They also provide means for determining the most economical combination of alinement, profile, and surface width that will effectively overcome the problem of slow moving vehicles on grades.

3. Driver behavior studies were made. During these studies the speed and transverse position of each vehicle and its spacing in relation to all other vehicles traveling in the same or opposing direction that might have influenced its speed or transverse position were recorded. At each location, data were obtained during periods when traffic increased from relatively light flows up to those at or approaching capacity conditions. The data that have been analyzed in detail include information for well over 1,000,000 vehicles at about 350 locations having various highway and roadside conditions. Additional data are also provided by the periodic speed studies conducted by the state highway departments at nearly 800 locations. To date, some 5,500 such studies have been made, including a total of nearly 2,000,000 vehicles.

The results of these studies have provided information regarding normal driving practices under various roadway and traffic conditions and have made possible the determination of the most appropriate combination of lane and shoulder width, the effect of curvature of varying degrees, the effect of curbs of various types, the effect of the presence of roadside objects such as narrow culverts or bridge rails that encroach on the normal shoulder width, and many other design details that have a considerable psychological effect on the driver.

4. Studies of traffic flow at intersections were conducted. From an analysis of data recorded at hundreds of the most heavily traveled intersections throughout the country, it has been possible to determine the effect of street width, parking regulations, turning movements, and many other factors on the possible and practical capacity of rural and urban intersections.

Application of Studies

These are only typical examples of the scope and type of studies that, in combination with evidence of traffic growth and other information obtained

by the planning survey organizations, form the basis of available geometric standards for highways. The results also provide information for adapting the many miles of existing roads and streets that must continue in use for extended periods of time.

The results of these studies, as they apply to highway capacity, have recently been published under one cover as a manual.[2] Many of the results, however, have been available in preliminary form and have been applied since 1947 by the more progressive highway organizations in their technical direction of the long-range highway needs studies that have been completed in several states.

No attempt will be made to present the details of this report, but a few of the most fundamental criteria will be pointed out as pertinent when selecting design standards for new construction or when revamping existing highways to accommodate increased traffic.

Desired Speed.—In open country, all but a few drivers at one time or another desire to travel between 50 and 70 miles per hr on highways of adequate design. Few exceed 70 miles per hr and most of the time the large majority travel between 45 and 55 miles per hr. On expressways in urban areas, most drivers desire to travel between 35 and 50 miles per hr during off-peak periods when traffic volumes are low. For similar conditions in rough or mountainous terrain, and on local roads and streets, desired speeds are 5 to 10 miles per hr slower.

Under the less favorable conditions of traffic density that occur during peak periods of flow, most drivers will voluntarily, and without feeling unduly restricted, lower their speeds to 45 miles per hr on main highways in rural areas and to 30 miles per hr on expressways in urban areas. Freedom to travel at these speeds with safety is the quality of service that highway and street systems must provide to meet the demands of traffic. There is no apparent justification for an added expenditure of highway funds to provide for higher speeds in the foreseeable future. Similarly, when drivers are forced to travel at unreasonably low speeds, the highway is overloaded or the design is inadequate.

Practical Capacity.—The highest hourly traffic volumes that a highway will accommodate safely at reasonable speeds is termed the practical capacity. The following list gives practical capacities of different types of facilities having 12-ft traffic lanes, excellent alinement, adequate shoulders, and no intersections at grade with major cross movements:

Type of highway	Capacity—in passenger cars per hour
Two-lane rural	900 total
Three-lane rural	1,500 total
Multilane rural	1,000 for each lane in the direction of heavier travel
Multilane urban expressway	1,500 for each lane in the direction of heavier travel

When present, the average commercial vehicle with dual rear tires can, for purposes of estimating capacity, be considered as 2 passanger cars in level terrain and as 4 passenger cars in rolling terrain.

Although some highways are now being constructed with 12-ft traffic lanes, excellent alinement, wide shoulders, and grade separations for cross traffic, most of our existing highways do not have these features, and it will be uneconomical and unnecessary to provide all of these features on many highways as they are constructed or rebuilt.

Effect of Limiting Factors.—The effect of these less favorable conditions on practical capacities has been obtained from the research studies. Nine-foot traffic lanes on two-lane roads, for example, have only 70% of the capacity of 12-ft lanes. A road with narrow shoulders and frequent obstructions within 2 ft of the pavement edge has only 80% of the capacity of a similar road with wide, clear shoulders. If a vehicle break down should occur, the capacity of the road with inadequate shoulders might be reduced as much as 60%. A vehicle break down occurs, on an average, at least once every 10,000 vehicle-miles of travel. To eliminate the obstruction to free flow and the resulting hazard of vehicles parked on the surface of rural highways while making emergency repairs or for other purposes, a shoulder width of 10 ft is required.

The effect of the alinement on the capacity of two-lane roads can now be determined from entirely new criteria developed from driver behavior and motor vehicle performance investigations. These criteria involve the percentage of the length of the highway on which the driver can see 1,500 ft ahead. A highway on which a driver can see 1,500 ft ahead during only 50% of the time as he travels at a uniform speed, for example, has only about 80% of the capacity of a highway on which the driver can always see 1,500 ft ahead. This comparison is applicable even though the designs of both highways are adequate for safe travel at 60 miles per hr during light traffic.

Interrelation of Design Elements

Most existing roads have been designed by considering various elements such as curvature, gradient, and sight distance independently, and applying to each some standard maximum or minimum. It is now known that the operating efficiency of a road can be predetermined only by considering these various elements in combination with one another, not independently. Adherence in the past to some maximum gradient to permit reasonable truck speeds on grades, for example, has resulted in the introduction of so much curvature that sometimes passing-sight distance has been nearly eliminated. Consequently, these roads now become badly congested at exceedingly low traffic volumes. The alinement and profile, together with other details of design that are selected for an important rural two-lane highway, can result in practical capacities ranging from 200 to 900 vehicles per hr and a corresponding (if not larger) variation in construction costs. Standards for various sections of highway must necessarily differ, therefore, with the volume and type of traffic for which the highway is being constructed or reconstructed. Any other approach to the problem would either be uneconomical or result in unsatisfactory operating conditions.

One of the more important elements limiting the capacity of any highway facility, especially city streets, is the intersection at grade. In the past far too little was known to relate effectively the roadway conditions and traffic control measures with the type and number of vehicles that an intersection would accommodate. It has been known for many years that a wide street will handle more traffic than a narrow street, that the elimination of curb parking and left turns will increase capacity, and that more vehicles can be accommodated on a one-way street than on a two-way street when other conditions are the same. What has not been known, however, is the quantitative effect of each of these and many other variables that affect the flow of traffic at intersections. Some are still unknown quantities, but the effect of many of the more important variables has been determined from research carried on over a sufficient period and with adequate repetition to justify confidence in the results. By application of this knowledge, it is possible to compare the capacity of an entire street system, as it is being operated, with the present or estimated future traffic demand. If the demand exceeds the capacity under the prevailing conditions, traffic control methods should first be appraised to determine the possibility of improvement. Next, the extent to which relief can be provided by recognized measures such as the elimination of curb parking, or adoption of one-way street systems, should be determined. Finally, if these measures will not provide the desired relief from congested traffic conditions, the benefits gained in traffic capacity by widening existing streets or constructing some new facilities should be considered.

The principles relating to highway capacity have been developed through years of research by many individuals and organizations. Their laboratory has been the highways and streets of the nation; their subjects have been millions of drivers operating vehicles under normal conditions. It is now the responsibility of engineers to apply the principles developed so that the safety and economy of highway transportation will be improved.